Response to Reviewer 1 for "Southern Ocean polynyas and dense water formation in a high-resolution, coupled Earth System Model" by Jeong et al.

We thank the reviewer for their helpful and constructive comments. Please find our responses below (the reviewer's comments are noted in italics and our reference to manuscript line numbers refers to the revised version of the manuscript).

... The study by Jeong et al. contributes to the study of coastal polynyas and the formation of dense/bottom water in GCMs... The manuscript is well-written and includes high-quality figures to support the main results. The methodology is sound and builds on state-of-the-art coupled Earth System Model (ESM) development. However, the discussion section is too brief and offers limited new insight into the main topic of missing dense-water formation in the coastal polynyas in GCMs and ESMs. I summarize key aspects the authors should address to improve the manuscript and its contribution to the ESM development near the Antarctic shelves:

1. Increasing the resolution of the E3SM improved the representation of coastal polynyas, but the associated dense-water formation was too weak and did not produce dense water with similar characteristics as the observations. What is your advice to the ESM community to further improve the polynya representation?

We believe that, while high horizontal resolution facilitates the formation of coastal polynyas because of the better resolved katabatic winds and ocean circulation near the coast, a proper cross-shelf ocean circulation also needs to be simulated. And that in turn is driven by well reproduced alongshore winds. We have now added a paragraph discussing this, as well as other points raised by the reviewer below, in the Discussion section: see text in blue starting from line

326.

2. You show that the winds over the continental shelves are too strong, resulting in a too strong Antarctic Slope Front which prevents shelf-ocean water exchange. What means can you do to get a better representation of the winds over the Antarctic shelves? Would it be possible to run the E3SM-HR with an idealized wind forcing near Antarctica to test the response to strong and weak wind scenarios? Including such a test in the manuscript would strongly increase the relevance of this study to the modeling community.

We thank the reviewer for these suggestions. Although we did not have the resources (including additional dedicated computational time) to run new E3SM experiments at the time of these revisions, we have carefully re-analyzed the E3SM-HR simulation by selecting years with strong and weak winds at the dense-shelf location (63°S). Specifically, the strong-wind (weak-wind) years were selected as years in which the wind speed for the winter season were higher (lower) than the top (bottom) 25% of the 30-year wind speeds. We were then able to compute strong-wind and weak-wind composites for cross-shelf ocean temperature, salinity, and alongshore velocity, and have included the results in a new figure, current Figure 8. These results support our hypothesis that the strong winds are an important contributor to the overly strong Antarctic Slope Front in E3SM-HR. We have added a discussion about this starting on line 288.

3. You describe plans to include landfast ice to improve the model further. How will the representation of landfast ice improve the model if the winds remain unchanged?

Landfast sea ice contributes to coastal polynya formation by effectively changing the coastline. This process, which is independent from the wind driving mechanism, is now briefly discussed in section 5, line 332.

4. The Southern Ocean is an area of upwelling. How well is the E3SM-HR representing the water mass characteristics in the Southern Ocean, and how are these characteristics affecting the formation of open-ocean polynyas?

We thank the reviewer for this question. We have now included a new figure in the Supplementary Material (Supplementary Fig. 1) showing T/S diagrams from E3SM-HR and WOA18. We have discussed these results on lines 235-239. Furthermore, we have added a sentence clarifying that the likely reason for OOPs formation in E3SM-HR is the concurrency of a strong Weddell Gyre and a weaker stratification (results not shown) in the interior Weddell Sea (lines 196-199).

5. The E3SM-HR does not include ice shelf cavities where dense water interacts with the ice shelf base to form the densest versions of shelf water (Ice shelf water). How are the missing ice shelves and the presence of ISW affecting the model performance?

We have added a sentence including the possible effects of ice shelves in the Discussion section (line 330).

6. The modeled sea ice is much thinner than the observations in OOP years over the whole WS. How is this affecting the dense water formation and the likelihood of increasing the lifespan of an OOP?

We assume that the reviewer is referring to Fig. 3a-c compared to Fig. 3d-f (please let us know if that is not the case). In that figure, we intend to use the observations only as reference, and not for model evaluation purposes. This is because OOP's are intermittent and highly variable events, and we cannot compare model and observation single events directly. We have added a sentence to clarify this in reference to Fig. 3a-c (see text in blue on line 179). Having said that, the question of how a less sea ice covered Weddell Sea would impact the lifespan of an OOP is an interesting one that deserves investigating in a separate study.

7. Are there any caveats in comparing the model with the SOSE database? Could it make sense to also compare the transects in Figures 7-9 with CTD sections?

We followed the reviewer's suggestion and replaced SOSE with CTD observations for the continental shelf sections in Figure 7. These are the same in-situ data used in Thompson et al. (2018).

Minor comments:

Line 159: It is very hard to see the "relatively higher latent heat flux... in East-Antarctica" in Fig1a.

We have now modified the color palette and masked out Antarctica in Figure 1a.

Line 256: It is very hard to see the easterly winds in figure 6b.

We have now updated Figure 6b, making the wind vectors more visible.